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The cross-sectional shape and circumference of the human trachea

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Summary

To design a large-volume, low-pressure cuff it is essential to take into consideration cross-sectional shape and circumference of human trachea. Two hundred adult tracheas were dissected and autopsy specimens examined. Cross-sectional tracheal shapes were studied and their circumference measured. There was a definite correlation between sex and the tracheal shapes studied. Forty five per cent of female tracheas were elliptical in shape and 38% were C shaped. The most common cross-sectional tracheal shapes in specimens obtained from male patients were the U shape (33%) and the elliptical (21%). Mean female tracheal circumference was 57.65 mm and mean male tracheal circumference was 68.75 mm. The implications of these findings are discussed and recommendations are made regarding cuff circumference and diameter.

Introduction

Most text books of human anatomy describe the cross-sectional shape of the adult trachea as C, U or nearly cylindrical shape *(1, 2, 12)*. The cuff of an inflated endotracheal tube is circular in cross-section. The mechanism of sealing the trachea varies with the type of cuff used. Low-volume, high pressure cuffs produce a tracheal seal by expanding in all directions, distorting the trachea in a circular fashion. Thus very high pressure between the cuff and the tracheal wall is necessary before a seal is created with a low-volume cuff. In many instances, the tracheal wall pressure exerted by such a cuff may far exceed capillary perfusion pressure and lead to ischaemia and mucosal ulceration. If the cross-section of the human trachea were always circular the sealing cuff pressure with a low-volume cuff would be lower and thus less traumatising. Recently high volume, low pressure cuffs have been introduced. These cuffs seal the trachea by conforming to its configuration without causing mucosal damage. With high-volume low pressure cuffs it has become possible to measure the cuff pressure against the tracheal mucosa as the pressure equals the intra-cuff pressure provided there is no tension in the wall of the cuff *(3)*.

To design such a cuff it is necessary to know the shape, circumference and diameter of the human trachea. For this reason cross-sectional tracheal shapes was studied and circumference and diameter of various specimens of trachea were measured.

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Material and methods

Two hundred adult tracheas were dissected and autopsy specimens obtained. All specimens were from non-intubated patients admitted to the Burnley group of hospitals. Care was taken not to include specimens from patients with pathological abnormality in and around the neck which would have distorted the shape of the trachea. The specimens were preserved in 10% formalin and stored in individual containers to prevent gravitational change in shape. All specimens were examined within a week of autopsy. Cross-sections were taken between the fifth and the seventh tracheal cartilage rings which would be expected to correspond to the position of the tracheal tube cuff.

The age, height, weight, sex and race of each patient were recorded from the case notes. The body surface area of each patient was calculated.

Tracheal shapes were classified according to the method described by Mackenzie *et al*(*4*). This involved the measurement of maximum transverse and anteroposterior diameters, the width of the posterior membrane, the angles between the posterior membrane and the cartilage of the tracheal ring and the circumference. Two observers independently carried out these measurements and classified the shapes of the cross-sections.

Results

Tracheal specimens were collected from 100 adult male and 100 adult female patients. One hundred and ninety-five patients were Anglo-Saxon and 5 were Oriental. Mean age was 68 years (range 32–90), mean weight was 64·8 kg (38–118) and mean height 164.5 cm (145–187.5). There was no correlation between patient age, weight, height, surface area and the tracheal shapes.

Six distinct tracheal cross-sectional shapes were observed. The most common was the elliptical trachea (33%) which had a larger transverse than anteroposterior diameter and the cartilage made an obtuse angle with the postrior membrane. The next most frequent tracheal shape was the C shape (26%). This shape had equal anteroposterior and transverse diameter and the cartilaginous portion formed an obtuse angle with the membranous portion. Four other shapes seen were the U shape (21.5%), the D shape (11%), the triangular (8%) and circular (0·5%). The U shape trachea had larger anteroposterior than transverse diameter and the cartilage made an obtuse angle with the posterior membrane. The D shape trachea had a large posterior membrane, anteroposterior diameter was much smaller than

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the transverse diameter and the cartilage formed an acute angle with the membranous portion. The triangular trachea had roughly equal transverse and anteroposterior diameter and the cartilage made an acute angle with the posterior membrane. Only one circular tracheal shape was seen. This had an almost complete ring of cartilage with a very narrow band of posterior membrane. The incidences of cross-sectional tracheal shapes is shown in Table 1.

There was a definite correlation between sex and the tracheal shapes studied. Of the 100 tracheas taken from females 45% were elliptical shaped and 38% were C shaped. No triangular shaped tracheas found in female specimens. On the other hand, the most common cross-sectional tracheal shapes found in specimens taken from males were the U shape (33%) and the elliptical (21%). There were equal numbers of D shaped and triangular shaped tracheas (16%). The incidences of anatomical cross-sectional shapes in adult males and females are shown on Tables II and III.

There were a number of asymmetrical cross-sectional tracheal shapes seen in specimens taken from both males and females. The asymmetry was mainly due to unequal angles between the cartilage and the posterior membrane. There was a higher incidence of asymmetrical cross-sectional shapes in tracheas from male patients (Table II and Table III).

Of the 200 specimens, 180 were similarly classified by independent observers. Differences in classification in the remaining specimens were due to the problem of differentiating triangular, D, C and elliptical shapes with nearly equal anteroposterior and transverse diameters and asymmetrical shape. These differences in classification between observers were resolved by mutual agreement. Figs. 1 and 2 show some of the cross-sectional tracheal shapes.

Tracheal circumference is shown in Table IV. Male tracheal circumference was significantly greater than female. Mean male tracheal circumference was 68.75 mm (range 60–79) and mean female tracheal circumference was 57.65 mm (range 50–69). Table V shows recommended cuff circumferences and diameters at residual volume for both adult males and females.

TABLE I *The incidences of cross-sectional tracheal shapes*

Shapes	C	U	D	E (Elliptical)	T (Triangular)	0 (Circular)
Number	52	43	22	66	16	1
Per cent	26	21·5	11	33	8	0·5

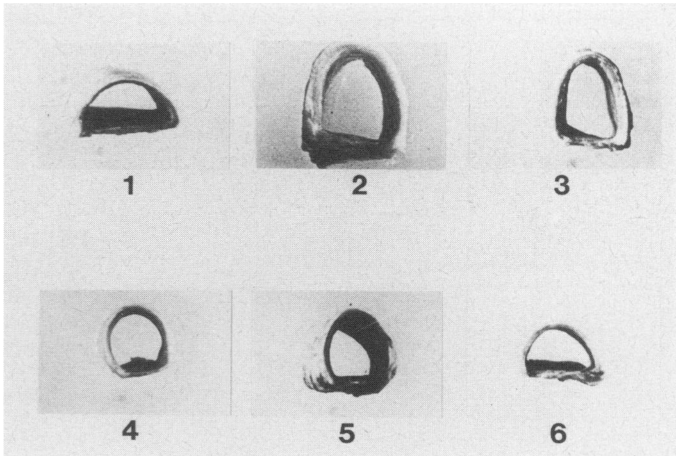

FIG. 1 (1) Symmetrical D shape (2) Symmetrical U shape. (3) Asymetrical U shape. (4) Symmetrical C shape. (5) Symmetrical U shape. (6) Asymmetrical D shape.

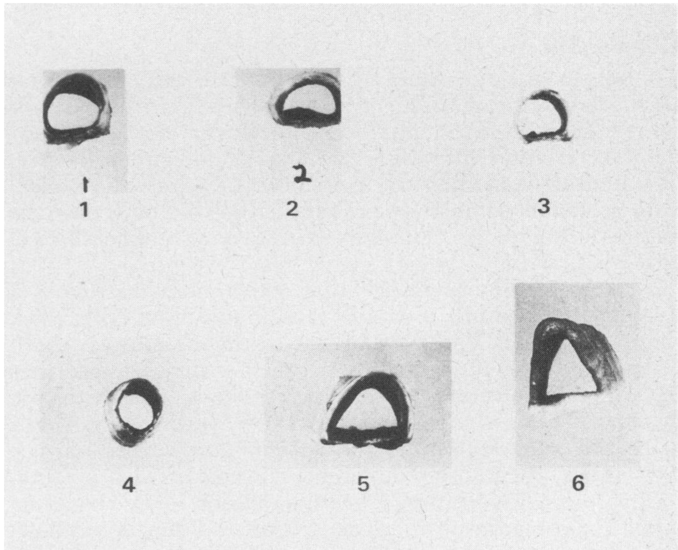

FIG. 2 (1) Symmetrical C shape. (2) Asymmetrical elliptrical shape. (3) Symmetrical elliptical shape. (4) Circular shape. (5) Asymmetrical triangular shape. (6) Symmetrical triangular shape.

TABLE II *Tracheal shapes in adult males*

	C		*U*		*D*		*E(Elliptical)*		*T (Triangular)*		*O (Circular)*	
	S	*A*	*S*	*A*	*S*	*A*	*S*	*A*	*S*	*A*	*S*	*A*
Number	13	1	23	10	15	1	15	6	10	6	0	0
Per cent	14		33		16		21		16		0	

S = Symmetrical. A = Asymmetrical.

TABLE III. *Tracheal shapes in adult females*

	C		*U*		*D*		*E (Elliptical)*		*T (Triangular)*		*O (Circular)*	
	S	*A*	*S*	*A*	*S*	*A*	*S*	*A*	*S*	*A*	*S*	*A*
Number	37	1	9	1	4	2	41	4	0	0	1	0
Per cent	38		10		6		45		0		1	

S = Symmetrical. A = Asymmetrical.

TABLE IV *Mean tracheal circumference (mm)*

	Adult male	*Adult female*
Number	100	100
Circumference	68·75	57.65
±SD mm	8.2	7.5

TABLE V Recommended cuff parameters

	Adult Male tubes	*Adult female tubes*
Cicumference (mm)	70	60
	80	70
Diameter (mm)	22.3	19.1
	25.5	22.3

Discussion

To our knowledge there is no evidence indicating that tracheal shapes are influenced by postmortem changes or preservation in formalin. The specimens showed considerable variation in cross-sectional shape and circumference. Our findings regarding the incidences of various anatomical cross-sectional tracheal shapes differ from that of Mackenzie and his associates (*4*). This may be due to racial differences of patients studied.

It is important to realize that the human trachea is a dynamic distensible organ of continuously varying size, shape and tone. The tone of the trachealis muscle which bridges the gaps posteriorly between the cartilaginous rings is mainly responsible for the varying size and shape of the trachea. Trachealis muscle tone varies with depth of anaesthesia and reacts to many commonly used drugs. Tracheal shape and circumference also alters with posture, particularly with position of head in relation to the rest of the body, coughing, inspiration, expiration and during mechanical ventilation. The increase in tracheal circumference is mainly due to bowing out of the posterior membrane.

It is now generally accepted that the small volume, high-pressure cuffs should be abandoned for prolonged use *(3, 5, 6)*. The most effective way of preventing tracheal injury is to use large residual volume, large diameter, low-pressure cuffs. However, there are certain dangers associated with over–inflation or under-inflation of low-pressure cuffs. Over–inflation of such a cuff may lead to application of excessive pressure against the tracheal mucosa causing destruction of ciliated epithelium and subsequent healing with epithelial metaplasia. This may result in the creation of a barrier for mucus transport causing chronic cough *(7)*. Other complications resulting from excessive lateral pressure on the tracheal wall include acute dilatation and rupture of the trachea, mucosal ulceration and deep tracheal wall pressure necrosis with subsequent stenosis. Underinflation of the cuff may allow eccentric positioning of the tube in the trachea, causing frictional mucosal erosion from the tip of the tracheal tube. There is also a potential danger of aspiration along the folds of excessive cuff material.

To date not much attention has been paid to the correct design of large volume. low pressure tracheal tube cuffs. In order to obtain a perfect tracheal seal one should not only take into account various cuff parameters and characteristics but also anatomical variation of tracheal shape, circumference and diameter. At present there is no uniformity of view as to the ideal length, shape, residual volume, circumference and diameter of the large-volume, low-pressure cuff. It has been suggested that the diameter of a large-volume cuff in relation to the trachea should be at least one and a half times the diameter of the trachea *(3, 8)*. With low-pressure cuffs, resting or exhalation intracuff pressure as low as 1 kPa can create a sufficient seal for positive pressure ventilation but such low-pressures do not necessarily protect against aspiration, particularly as the large cuffs are prone to produce longitudinal foldings of cuff material through which liquid may pass down the trachea *(9, 10)*. Perhaps it is most appropriate to have a cuff circumference and diameter at residual volume close to that of the human trachea *(11)*. Although the tracheal diameter increases during the inspiratory phase of mechanical ventilation, The increased airway pressure applied to the cuff would in turn help to maintain a perfect tracheal seal. In males, cuffs with circumferences of 70 mm and 80 mm and in females, cuffs with circumferences of 60 mm and 70 mm would create a seal in the trachea against airleak and aspiration at intracuff pressure of 2.5 to 3kPa. Thus it may be prudent to have two sizes of cuffs for both adult males and females with average and maximum human tracheal circumference. Manufacturers should be encouraged to standardise tracheal tubes not only by internal tube diameter but also with cuff circumference at residual volume to determine the best fit within the trachea.

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